University of Wollongong
Research Online

Faculty of Science, Medicine and Health - Papers: part A | Faculty of Science, Medicine and Health

1-1-2013

Displacement plethysmographs for measuring limb segment blood flow (forearm, hand, calf, foot) with independent control over local skin temperature: a project for an older tool

Joanne N. Caldwell Odgers
University of Wollongong, joc@uow.edu.au

David J. R Hoyle
University of Wollongong, dh509@uowmail.edu.au

Nigel A.S Taylor
University of Wollongong, ntaylor@uow.edu.au

Follow this and additional works at: https://ro.uow.edu.au/smhpapers

Part of the Medicine and Health Sciences Commons, and the Social and Behavioral Sciences Commons

Recommended Citation
Caldwell Odgers, Joanne N.; Hoyle, David J. R; and Taylor, Nigel A.S, "Displacement plethysmographs for measuring limb segment blood flow (forearm, hand, calf, foot) with independent control over local skin temperature: a project for an older tool" (2013). *Faculty of Science, Medicine and Health - Papers: part A*. 927.
https://ro.uow.edu.au/smhpapers/927

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

Displacement plethysmographs for measuring limb segment blood flow (forearm, hand, calf, foot) with independent control over local skin temperature: a project for an older tool

Abstract

Measuring cutaneous blood flow is an essential building block for understanding thermoeffector responses to changes in central and peripheral tissue temperatures. Under thermoneutral conditions, skin blood flow modifications are the primary pathway for heat exchange. Outside this zone, flow changes provide information pertaining to the thermoregulatory control mechanisms that modulate vasomotor tone. Whilst there are numerous methods available for measuring regional blood flow in humans, the most common method for evaluating the cutaneous flow is via venous-occlusion plethysmography, which has been used for over a century (an older tool), with strain-gauge plethysmographs being most commonly used today.

Keywords

control, independent, foot, calf, hand, forearm, limb, blood, measuring, plethysmographs, flow, tool, older, project, temperature, skin, displacement, local, segment, over

Disciplines

Medicine and Health Sciences | Social and Behavioral Sciences

Publication Details

Caldwell Odgers, J. N., Hoyle, D. J. R. & Taylor, N. A.S. 2013, 'Displacement plethysmographs for measuring limb segment blood flow (forearm, hand, calf, foot) with independent control over local skin temperature: a project for an older tool', in J. D. Cotter, S. JE. Lucas & T. Mundel (eds), Proceedings of the 15th International Conference on Environmental Ergonomics, International Society for Environmental Ergonomics, New Zealand, pp. 165-167.

This conference paper is available at Research Online: https://ro.uow.edu.au/smhpapers/927

Displacement plethysmographs for measuring limb segment blood flow (forearm, hand, calf, foot) with independent control over local skin temperature: A project for an older tool

*Joanne N. Caldwell, David J.R. Hoyle, Nigel A.S. Taylor**
Centre for Human and Applied Physiology, University of Wollongong, Wollongong, Australia
*corresponding author: Nigel_Taylor@uow.edu.au

Introduction

Measuring cutaneous blood flow is an essential building block for understanding thermoeffector responses to changes in central and peripheral tissue temperatures. Under thermoneutral conditions, skin blood flow modifications are the primary pathway for heat exchange. Outside this zone, flow changes provide information pertaining to the thermoregulatory control mechanisms that modulate vasomotor tone. Whilst there are numerous methods available for measuring regional blood flow in humans, the most common method for evaluating the cutaneous flow is via venous-occlusion plethysmography, which has been used for over a century (an older tool), with strain-gauge plethysmographs being most commonly used today.

Unfortunately, with these devices, it is often very difficult to investigate the impact of changes in local skin temperature on segmental blood flow. Since this is a research interest of the current investigators (see accompanying communication), a method was required that would allow for the independent manipulation, and the subsequent clamping of core, mean skin and local skin temperatures. With water immersion able to elicit rapid tissue temperature changes, it was decided that water-filled plethysmographs would serve this objective. Herein is described the construction of four displacement plethysmographs (forearm, hand, calf, foot), along with the validation of one of these devices (forearm) against a strain-gauge plethysmograph.

Methods

Each of the four plethysmographs was constructed using the same basic design (Figure 1). The main body (aluminium shell) was divided into two independent, water-filled compartments: internal and external chambers. Water in the former chamber was used to change local skin temperature and, through its displacement, to quantify changes in limb segment blood flow. The latter chamber had a water volume approximately ten times that of the inner chamber. This water was continuously circulated through water baths, with its temperature being tightly regulated. Due to the water volume difference between these compartments, the water temperature of the inner chamber could be changed relatively quickly (< 10 min) to elicit local skin temperature changes.

The inner chamber was defined by its rigid aluminium (outer) wall and a tightly fitting (inner) latex sleeve, glove or sock that covered the limb segment in question, which itself was housed within the plethysmograph. These latex membranes were made within the laboratory using plaster moulds. A rigid flange (Figure 1A) secured each membrane to the main chamber, rendered this compartment water tight. Protruding from the internal chamber were two aluminium pipes (Figure 2); one was the measurement arm (housing a glass expansion adapter with two-hole rubber stopper, glass pipette and pressure transducer), and the other was for filling the inner chamber with water and for calibration. The latter pipe remained closed during testing, whilst the former, also closed to the atmosphere, provided a trapped air space into which water could be displaced following venous occlusion. Changes in this displaced water volume were detected using a differential pressure transducer. Digital outputs from the transducer were displayed and collected onto a computer. It was assumed that, within resting states, changes in these segmental blood flows were due solely to variations in the cutaneous vascular flow.

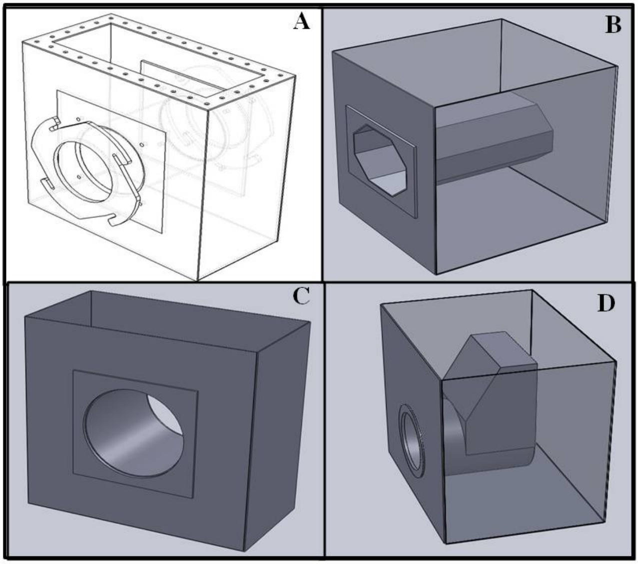

Figure 1. Three-dimensional diagrams (not to scale) showing the internal and external chambers of four, water-filled plethysmographs (forearm (**A**), hand (**B**), calf (**C**), foot (**D**).

Having completed this construction, it was necessary to evaluate the precision with which blood flow could be measured, in comparison with a commercially available technique (mercury-in-silastic strain-gauge) under conditions of relevance to future experimental applications. Therefore, male (n=4) and female (n=4) subjects completed two separate trials, with limb segment (forearm) blood flow measured using two plethysmographic techniques: ***Trial 1*:** strain-gauge plethysmograph; ***Trial 2***: water-filled plethysmograph. Within each trial, skin blood flow was measured with the local skin being at two different temperatures (mid-dorsal forearm): firstly thermoneutral (31.6°C ±0.4) and then heated (37.4°C ±0.5).

Results and Discussion

When averaged across the entire trial, there were no significant differences in core temperature between the two trials (***Trial 1***: 36.9°C; ***Trial 2**:* 37.0°C; p>0.05). Similarly, there were no differences in either mean skin temperature (***Trial 1***: 31.6°C; ***Trial 2***: 31.1°C; p>0.05) or mean arterial pressure (***Trial 1***: 88.3 mm Hg; ***Trial 2***: 88.1 mm Hg; p>0.05) between these trials. This outcome was important, since it was essential that cutaneous blood flow was not influenced by thermoregulatory or cardiovascular reflexes.

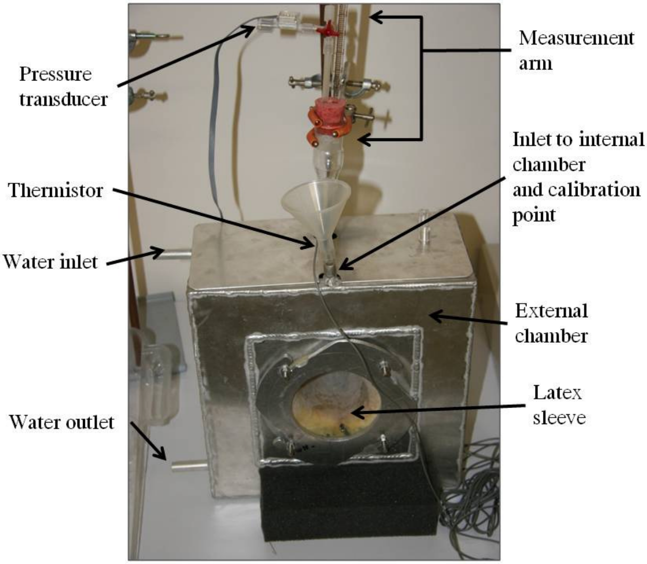

Figure 2. A displacement plethysmograph for measuring forearm blood flow.

During the thermoneutral phase of each trial, cutaneous blood flow was 1.96 mL·100 mL^{-1}·min^{-1} (***Trial 1***) and 1.47 mL·100 mL^{-1}·min^{-1} (***Trial 2***; p>0.05). Local heating within each trial elicited significantly higher blood flows (p<0.05), but these did not differ significantly between techniques (***Trail 1***: 5.53 mL·100 mL^{-1}·min^{-1}; ***Trial 2***: 5.06 mL·100 mL^{-1}·min^{-1}; p>0.05). These results indicate that the water-filled plethysmograph provided a valid method for measuring forearm blood flow.

Conclusion

This validation was an important outcome, since not only did it allow for a thermoneutral comparison, but it permitted a validation when local skin temperature was elevated. In a subsequent communication to this society, we report changes in blood flow from four limb segments measured using these plethysmographs, with core and mean temperatures modified and clamped, and then when local skin temperatures were elevated and reduced during this thermal clamping. Moreover, inter-segmental comparisons of these vascular responses can now be made across identical thermal states, and this work has provided the foundation upon which several subsequent experiments are currently being developed.